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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

[redacted] MEMORANDUM REPORT

for

Army Air Corps

OBSERVATIONS IN FLIGHT OF THE REGION OF STALLED FLOW OVER THE BLADES OF THE KELLETT YG-1B TAPERED-BLADE AUTOGIRO ROTOR

By F. B. GUSTAFSON

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SUMMARY

In conjunction with a series of tests requested by the Army Air Corps on a new set of tapered rotor blades, of NACA 230 series section and built for the Kellett YG-1B autogiro, it was convenient to supplement previous studies of the region of stalled flow on rotors by making photographic observations of the flow over the blades in flight. These observations are described in this report. It is shown that the maximum radius stalled on the new rotor increases more rapidly with tip-speed ratio than was true on the rectangular-blade, Göttingen 606 section rotor previously tested on the same ship, though the increase in importance of the stalled region is not as decisive as consideration of the change in section would suggest. The increased loss in the stalled region is felt to be at least a contributing cause in the failure of the new blades to increase the top speed of the machine.

INTRODUCTION

In a previous report on stalled flow over rotor blades (reference 1), experiments were described which indicated that this stalled flow is of more importance to the efficiency of rotorcraft than would be anticipated from theoretical treatments of the subject; the experimentally determined regions were markedly larger than the theoretical regions. In a subsequent paper (reference 2) the amount of power represented by the stalled region at the higher tip-speed ratios was calculated. It was shown in the theoretical portion of this paper that the power loss calculated depends quite critically on the angle of attack at which the blade section is assumed to stall. The angle used is simply the stalling angle at the appropriate Reynolds number as obtained from static tests; there is no guarantee that the conditions of flow in the rotor will not alter the relative stalling angles of the various sections. The experimental data of reference 1 covered only one airfoil section and hence did not indicate whether or not the assumptions of the theory are valid in this respect.

While making a photographic study of the blade motion of a new set of tapered rotor blades of different airfoil section for the Kellett autogiro, as requested by the Army Air Corps, it was found possible to attach tufts to the blade upper surfaces without interfering with blade motion observations, and thus obtain records of the flow over these blades similar to those obtained for the previous set of blades. In addition to providing further comparisons with theory, it was expected that the tuft records might reveal the reason that the new blades, with their lower drag section, did not add to the top speed of the machine.

This report describes the analysis of and conclusions from these tuft records, which were obtained at Langley Field, Va., during November 1939.

APPARATUS AND TESTS

The machine used in these tests was the Kellett YG-1B autogiro equipped with tapered blades of modified 23012 section. The blades taper in plan form from 18 inches at the center of the rotor to 12 inches at the blade tip, and in section thickness from 16 percent at center to 10 percent at the tip. These figures are based on extensions of the outlines of the linearly tapering portion of the blades, the root and tip being suitably modified. The modification of the standard NACA 230 series section consists in reflexing the last $1\frac{1}{4}$ inches of the trailing edge 0.86° to obtain zero moment coefficient.

Streamers, some wool and some silk, were mounted on one of the blades at various radii. The silk tufts were mounted in pairs as described in reference 1. The wool tufts consisted of single strands of wool yarn $1\frac{1}{2}$ inches long, placed directly behind one another at intervals of 2 inches. A motion-picture camera was mounted on the rotor hub aiming outward over this blade. The camera rotated with the blades and took about 10 pictures per revolution. The azimuth position of the camera and the blade at the instant each picture was taken was established by means of a line on the film, breaks in which indicated that contacts on the rotor hub at one of six known azimuths had been crossed. Records about 4 seconds in length were taken at indicated air speeds from 40 to 110 miles per hour, corresponding to tip-speed ratios from 0.15 to 0.35. The flight altitudes ranged from 1500 to 3500 feet. Records were taken in level flight and then duplicated in glides.

RESULTS

The records were analyzed just as described in reference 1. Figure 1 shows the azimuth angles at which the flow changed from unstalled to stalled and vice versa plotted against tip-speed ratio. Figure 2 shows the outer boundaries of the stalled areas at four tip-speed ratios, as obtained by cross-plotting from the curves of figure 1. For comparison, the corresponding curves for tip-speed ratios of 0.20 and 0.35 respectively as obtained in the experiments of reference 1, on the rectangular blades, are included. As a matter of interest, four records were analyzed which were taken during right and left banks. These records were a part of the series described in reference 3. To avoid confusion the values obtained are plotted in a separate figure (fig. 3) along with the appropriate portions of the faired curves of figure 1.

DISCUSSION

Figure 2 affords a comparison between an airfoil whose static stalling angle is 19.7° and one whose static stalling angle is about 15°. Unfortunately there are other differences as well, the rotor with the 15° stalling angle being tapered in both plan and section whereas the other is rectangular in both plan and section. The 15° value for the tapered blades is the value at 0.7 radius for a Reynolds number of about 1,200,000, which Reynolds number corresponds to a tip-speed ratio of 0.35 with the blade on the retreating side of the disk. The effect of the taper in section is to increase the stalling angle one or two degrees toward the inboard sections and reduce it one or two degrees towards the tip. The effect of taper in plan form would be felt chiefly through its effect on inflow distribution over the disk. Figure 2 shows that the tapered blades stall out to a distinctly larger radius than the rectangular ones; they appear equal or superior to the rectangular blades farther inboard however, a result which is partially explainable by consideration of the taper. Inasmuch as the larger radii represent relatively greater power loss (see fig. 3 of reference 2) the stalled region is consuming more power in the case of the tapered blades than in the case of the rectangular blades. Using the contours of figure 2 together with the charts of reference 2, it appears that, at $\mu = 0.35$, the stalled area accounts for roughly 10 percent of the rotor drag in the case of the tapered blades.

Figure 4 shows the rates of increase of the maximum radii stalled with tip-speed ratio. It may be noted that, according to the extrapolation of the test points, the tapered blades are stalled nearly to the tip at the top speed of the machine, or at a value of μ of about 0.40. This confirms the idea that increased power loss in the stalled region is a factor in the failure of the new blades to increase the top speed of the machine. The extrapolation is felt to be conservative because (1) theory shows the rate of increase of maximum radius stalled to be greater than linear, and (2) the rate of decrease of stalling angle with radius, for the tapered blades, becomes greater as the thin sections of the tip are reached.

Figure 3 compares stalling and unstalling values obtained during manuevers, specifically right and left banks, with the faired curves obtained from steady-flight data. The records taken during manuevers were more difficult to evaluate accurately because the tip-speed ratio changed throughout the record; nevertheless it is felt that the check is sufficiently good to indicate that the boundaries of the stalled region remain approximately normal during maneuvers. The changes from unstalled to stalled and vice versa appear to come a little earlier than normal during the right bank and a little later than normal during the left bank, but the deviations are not decisive and furthermore do not change the area included in the stalled region.

Comparison of figure 1 of this report with figure 2 of reference 1 will show that the scatter of the values is considerably less in these tests. Further, it was found that the values were duplicated quite closely when the records were re-read, within about 3° in azimuth for the most part. It was also noted that the values for the glides almost duplicated the corresponding level-flight tests, even when both fell somewhat off the faired curve. This increased accuracy results from several sources. First, a faster shutter speed was used on the camera, with clearer pictures resulting. Second, the use of a built-in timing device instead of flying away from the sun resulted in clearer pictures because the flights were made with the sun more directly overhead, and also resulted in more accurate determination of azimuth values by reason of requiring less interpolation. Third, the wool yarn tufts tried proved far superior to silk ribbons; their positions were less susceptible to varying interpretations and they photographed more clearly.

CONCLUSIONS

1. The stalled region on the YG-1B tapered-blade autogiro rotor becomes so large as to represent an important factor in the rotor drag at the higher tip-speed ratios, though not the critical factor at the tip-speed ratios reached in these tests.

2. The maximum radius stalled increases more rapidly, with increasing tip-speed ratio, for the tapered blades of the 230 series section than for the rectangular blades of Göttingen 606 section.

3. The increased loss in the stalled region is felt to be at least a contributing cause in the failure of the new blades to increase the top speed of the machine.

4. Tests on a larger number of sections, and preferably with fewer secondary differences between the rotors, will be necessary before it will be possible to state whether the theory gives the proper picture of the increase of importance of the stalled region with decrease in static stalling angle of the blade section.

5. Maneuvers, specifically right and left banks, do not markedly affect the boundaries of the stalled region on the autogiro rotor.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 17, 1940.

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EAE

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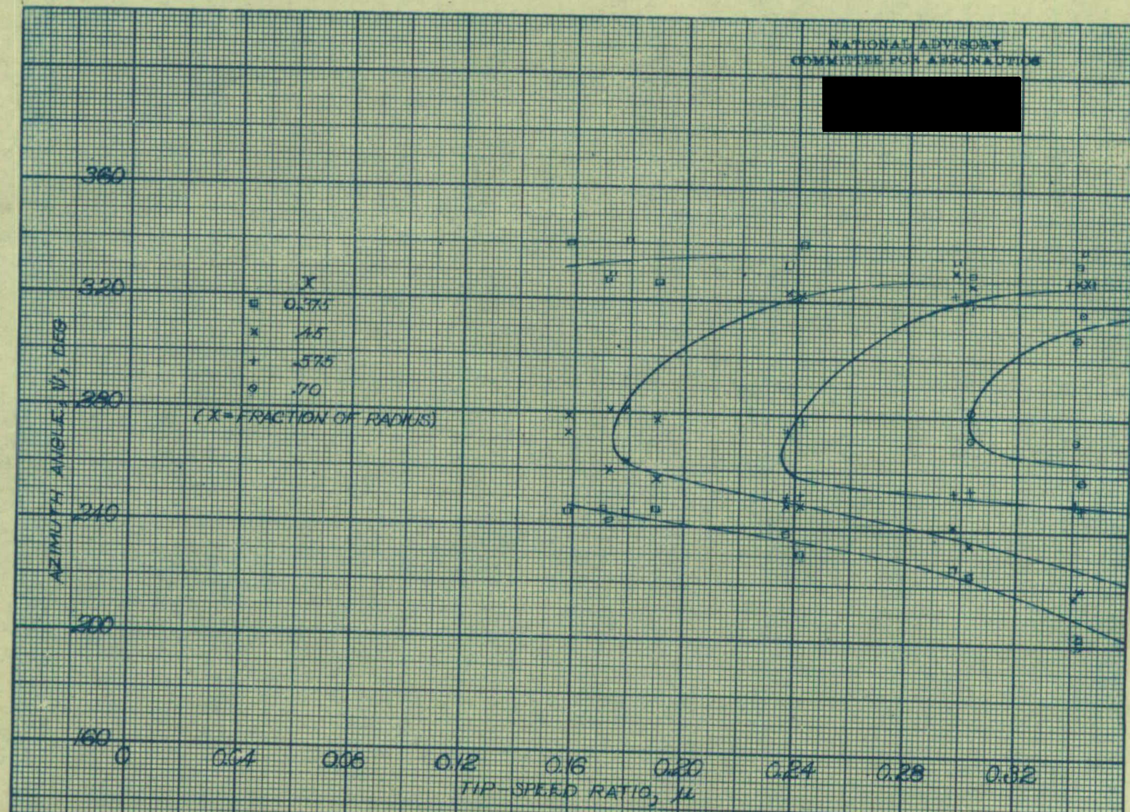

Figure 1. - Experimental values of the azimuth angles at which the blade element enters and leaves the region of stalled flow. The YG-1B autogiro rotor, equipped with tapered blades of NACA 23012 (modified) section.

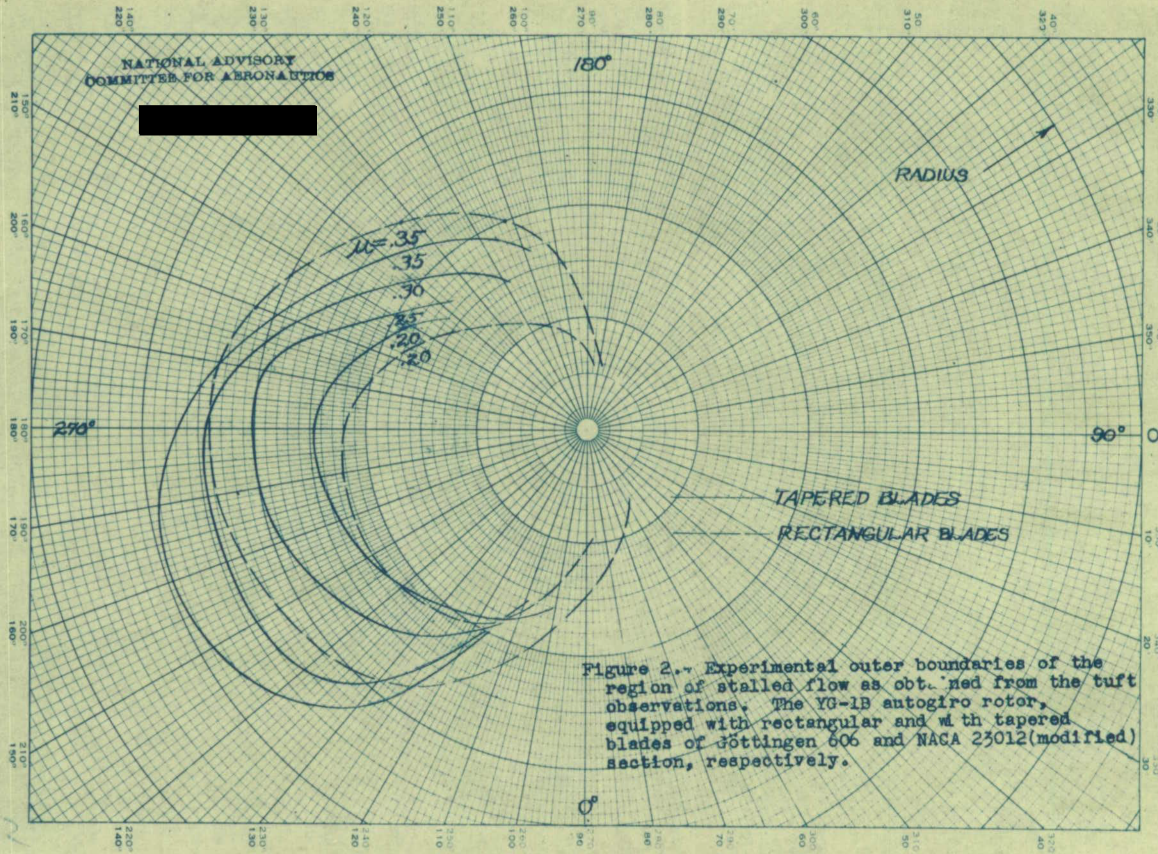

Figure 2.- Experimental outer boundaries of the region of stalled flow as obtained from the tuft observations. The YG-1B autogiro rotor, equipped with rectangular and with tapered blades of Göttingen 606 and NACA 23012(modified) section, respectively.

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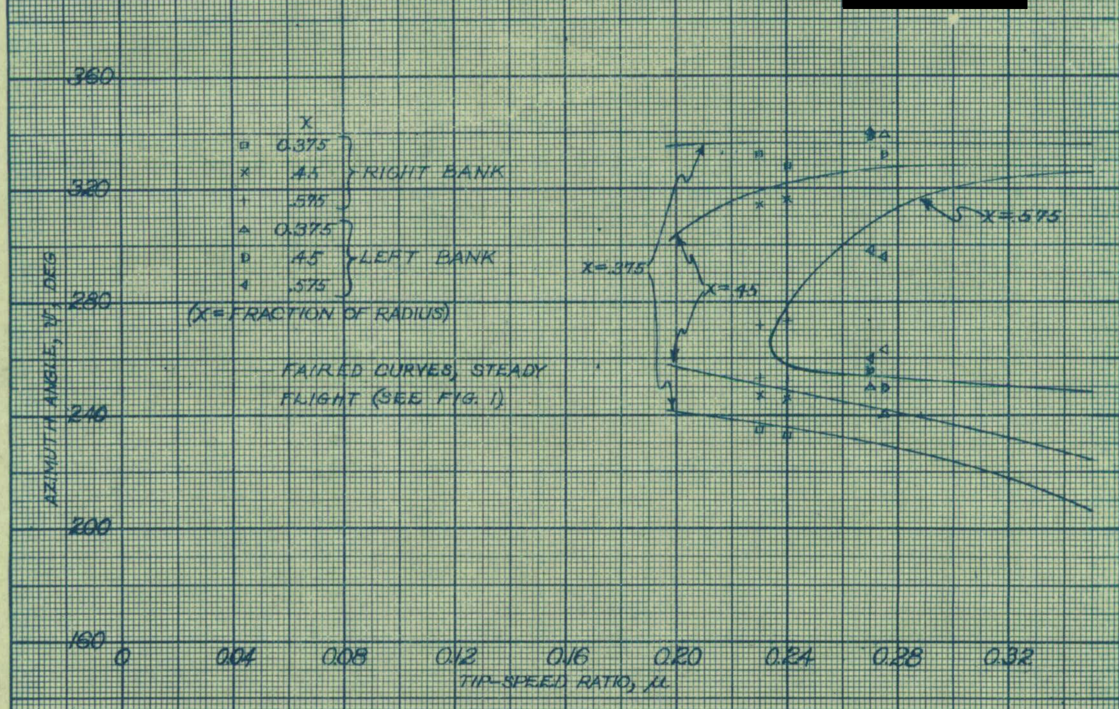

Figure 3. - Experimental values of the azimuth angles at which the blade element enters and leaves the region of stalled flow. Comparison of values obtained during maneuvers with faired curves obtained from steady flight data. The YG-1B autogiro rotor, equipped with tapered blades of NACA 23012 (modified) section.

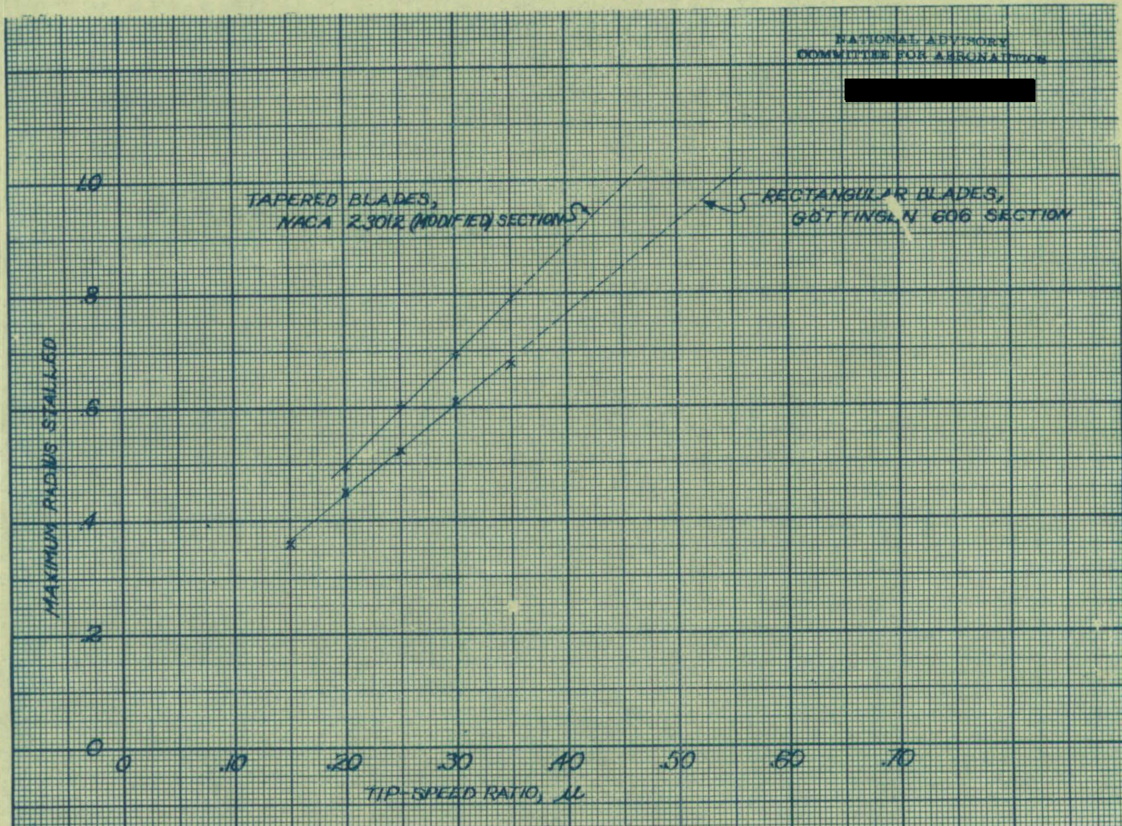

Figure 4. - Maximum radius of stall versus tip-speed ratio, for the YG-1B autogiro rotor equipped with rectangular blades of Göttingen 606 section, and with tapered blades of NACA 23012 (modified) section, respectively.